Computer Networks

Quanlong Li

Chapter 6: The Physical Layer

Our goals:

- understand principles behind physical layer services:
  - Data Transmission
  - Data Encoding
  - Transmission Media
  - The Data Communications Interface

Overview:

- Data Transmission
  - Terminology
- Data Encoding
  - Encoding Techniques
  - Digital Data, Digital Signal
  - Encoding Schemes
- Transmission Media
- The Data Communications Interface
  - Asynchronous and Synchronous Transmission
  - Interfacing

Terminology (1)

- Transmitter
- Receiver
- Medium
  - Guided medium
    - e.g. twisted pair, optical fiber
  - Unguided medium
    - e.g. air, water, vacuum

Terminology (2)

- Direct link
  - No intermediate devices
- Point-to-point
  - Direct link
  - Only 2 devices share link
- Multi-point
  - More than two devices share the link

Terminology (3)

- Simplex
  - One direction
    - e.g. Television
- Half duplex
  - Either direction, but only one way at a time
    - e.g. police radio
- Full duplex
  - Both directions at the same time
    - e.g. telephone

Spectrum & Bandwidth

- Spectrum
  - range of frequencies contained in signal
- Absolute bandwidth
  - width of spectrum
- Effective bandwidth
  - Often just bandwidth
  - Narrow band of frequencies containing most of the energy
- DC Component
  - Component of zero frequency

Data Rate and Bandwidth

- Any transmission system has a limited band of frequencies
- This limits the data rate that can be carried

Analog and Digital Data Transmission

- Data
  - Entities that convey meaning
- Signals
  - Electric or electromagnetic representations of data
- Transmission
  - Communication of data by propagation and processing of signals

Data

- Analog
  - Continuous values within some interval
  - e.g. sound, video
- Digital
  - Discrete values
  - e.g. text, integers

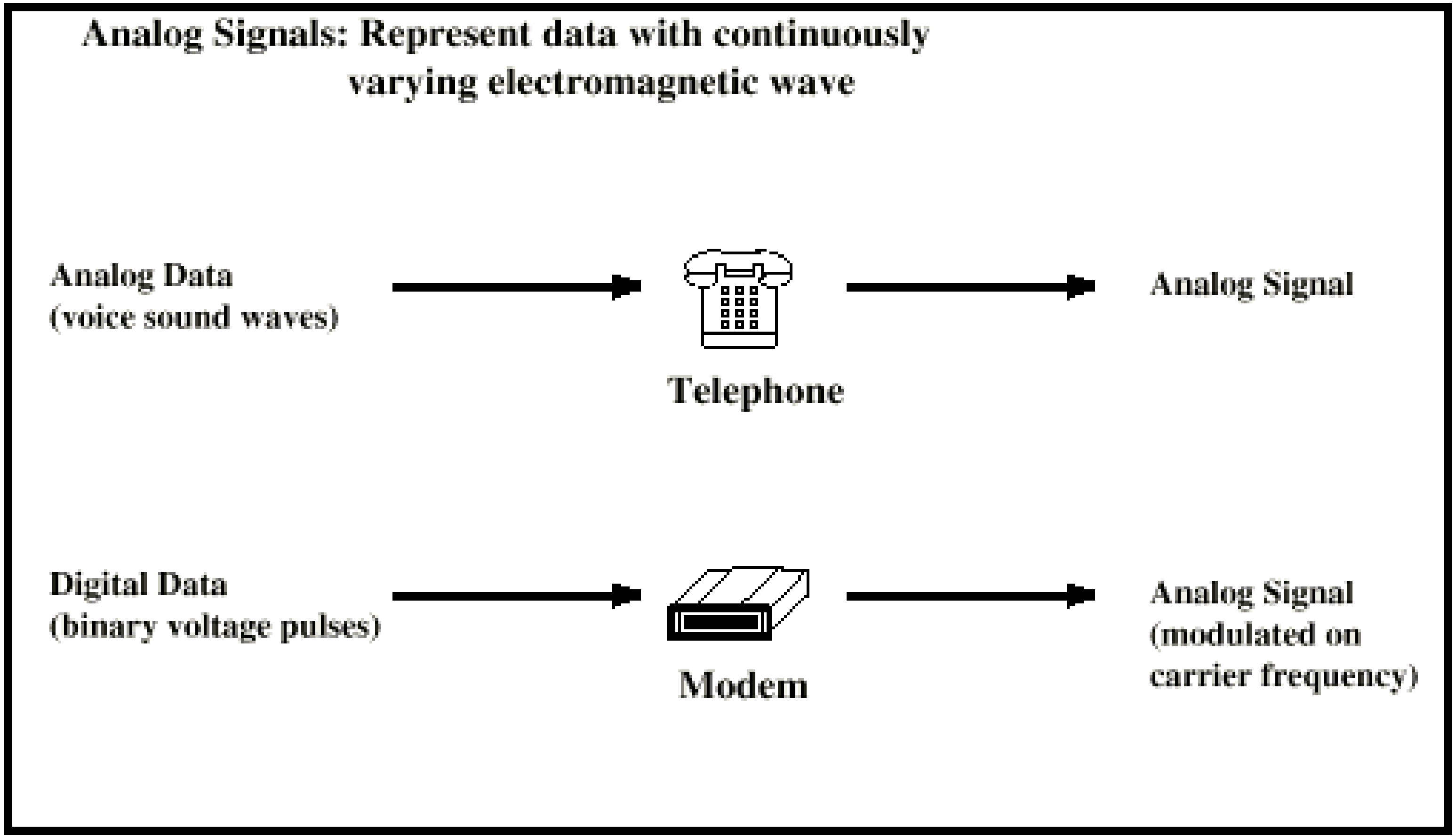
Signals

- Means by which data are propagated
- Analog
  - Continuously variable
  - Various media
    - wire, fiber optic, space
  - Speech bandwidth 100Hz to 7kHz
  - Telephone bandwidth 300Hz to 3400Hz
  - Video bandwidth 4MHz
- Digital
  - Use two DC components

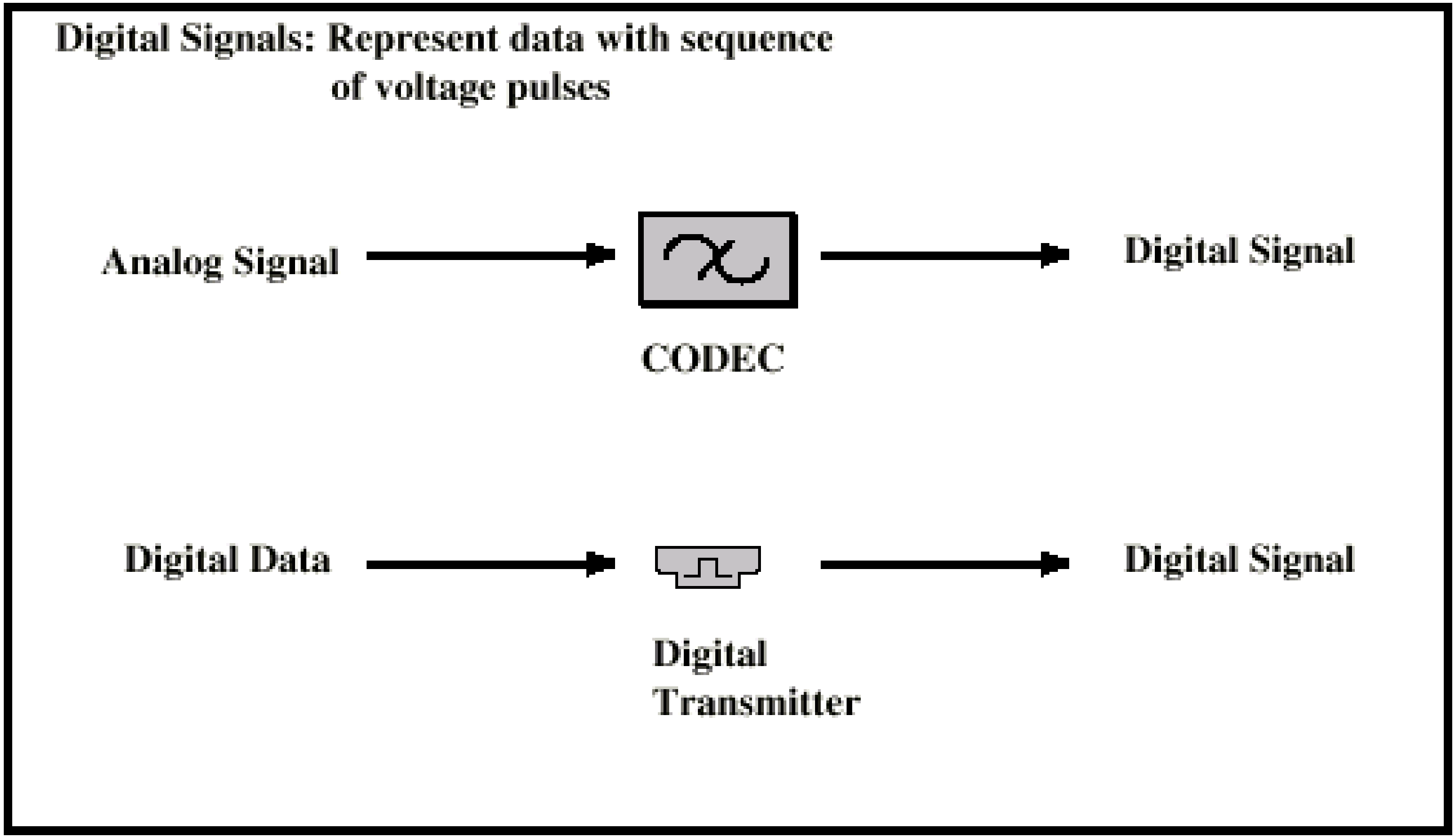
Data and Signals

- Usually use digital signals for digital data and analog signals for analog data
- Can use analog signal to carry digital data
  - Modem
- Can use digital signal to carry analog data
  - Compact Disc audio

Analog Signals Carrying Analog and Digital Data



Digital Signals Carrying Analog and Digital Data



Analog Transmission

- Analog signal transmitted without regard to content
- May be analog or digital data
- Attenuated over distance
- Use amplifiers to boost signal
- Also amplifies noise

Digital Transmission

- Concerned with content
- Integrity endangered by noise, attenuation etc.
- Repeaters used
- Repeater receives signal
- Extracts bit pattern
- Retransmits
- Attenuation is overcome
- Noise is not amplified

Channel Capacity

- The maximum rate at which data can be transmitted over a given communication path (channel)
- Data rate
  - In bits per second
  - Rate at which data can be communicated
- Bandwidth
  - In cycles per second of Hertz
  - Constrained by transmitter and medium
- Nyquist Bandwidth (Nyquist formulation)
  - Noise free channel
  - $C=2B\log_2^M$
    - C-channel capacity, B-bandwidth, M-the number of discrete signal

For example

在无噪声情况下，若某通信链路的带宽为3 kHz，采用4个相位、每个相位具有4种振幅的QAM调制技术，则该通信链路的最大数据传输速率是

A. 12 kbps　　B. 24 kbps

C. 48 kbps　　D. 96 kbps

答案：B

Channel Capacity

- Shannon Capacity Formulation
  - Noise channel
  - At a given noise level, the higher the data rate, the higher the error rate
  - $C=B\log_2^{(1+S/N)}$
    - S/N-signal-to-noise ratio
      - The ratio of the power of signal to the power of noise
  - S/N is often reported in decibels (dB):
    - $(S/N)_{dB}=10\log_{10}^{(\text{Signal power/Noise power})}$

Encoding Techniques

- Digital data, digital signal
- Analog data, digital signal
- Digital data, analog signal
- Analog data, analog signal

Digital Data, Digital Signal

- Digital signal
  - Discrete, discontinuous voltage pulses
  - Each pulse is a signal element
  - Binary data encoded into signal elements

Terms

- Unipolar
  - All signal elements have same sign
- Polar
  - One logic state represented by positive voltage the other by negative voltage
- Data rate (Bit rate-R)
  - Rate of data transmission in bits per second
- Modulation rate (Baud rate-B)
  - Rate at which the signal level changes
  - Measured in baud = signal elements per second
  - $R=B\log_2 M$; M-Number of states of code element
- Duration or length of a bit
  - Time taken for transmitter to emit the bit
- Mark and Space
  - Binary 1 and Binary 0 respectively

Encoding Schemes

- Nonreturn to Zero-Level (NRZ-L)
- Nonreturn to Zero Inverted (NRZI)
- Bipolar -AMI
- Pseudoternary
- Manchester
- Differential Manchester

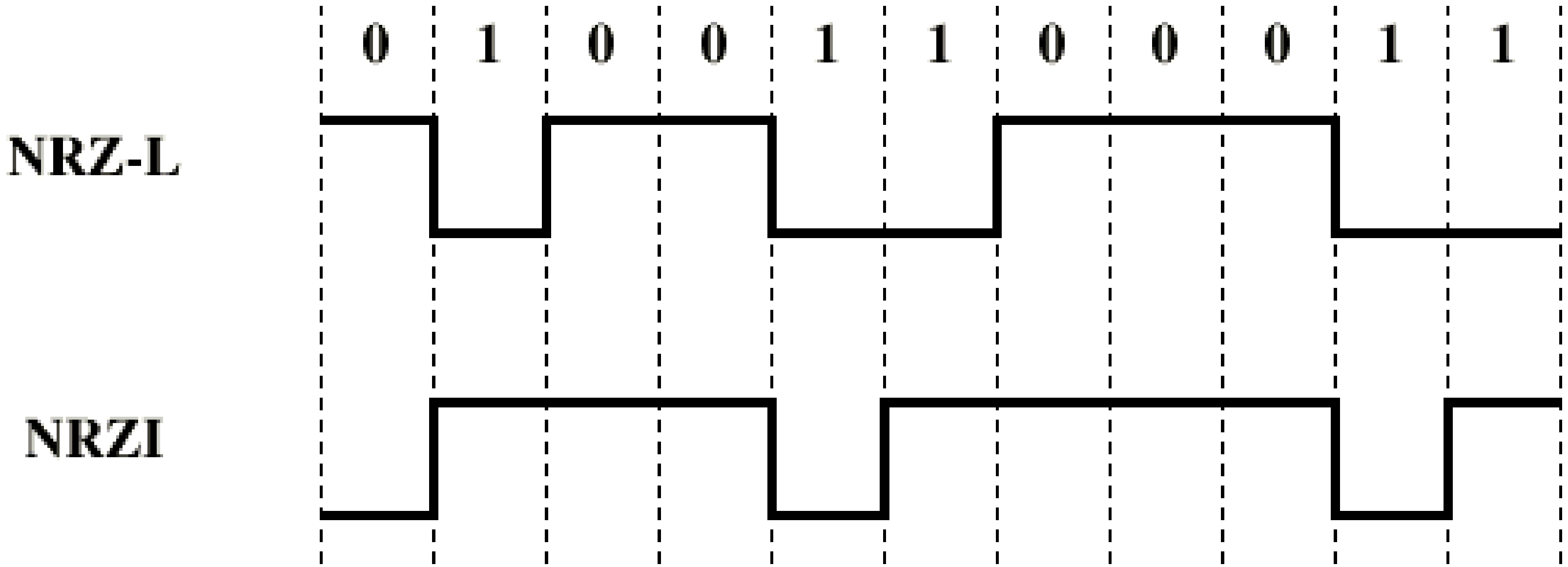
Nonreturn to Zero-Level (NRZ-L)

- Two different voltages for 0 and 1 bits
- Voltage constant during bit interval
  - no transition I.e. no return to zero voltage
- e.g. Absence of voltage for zero, constant positive voltage for one
- More often, negative voltage for one value and positive for the other
- This is NRZ-L

Nonreturn to Zero Inverted

- Nonreturn to zero inverted on ones
- Constant voltage pulse for duration of bit
- Data encoded as presence or absence of signal transition at beginning of bit time
- Transition (low to high or high to low) denotes a binary 1
- No transition denotes binary 0
- An example of differential encoding

NRZ



Differential Encoding

- Data represented by changes rather than levels
- More reliable detection of transition rather than level
- In complex transmission layouts it is easy to lose sense of polarity

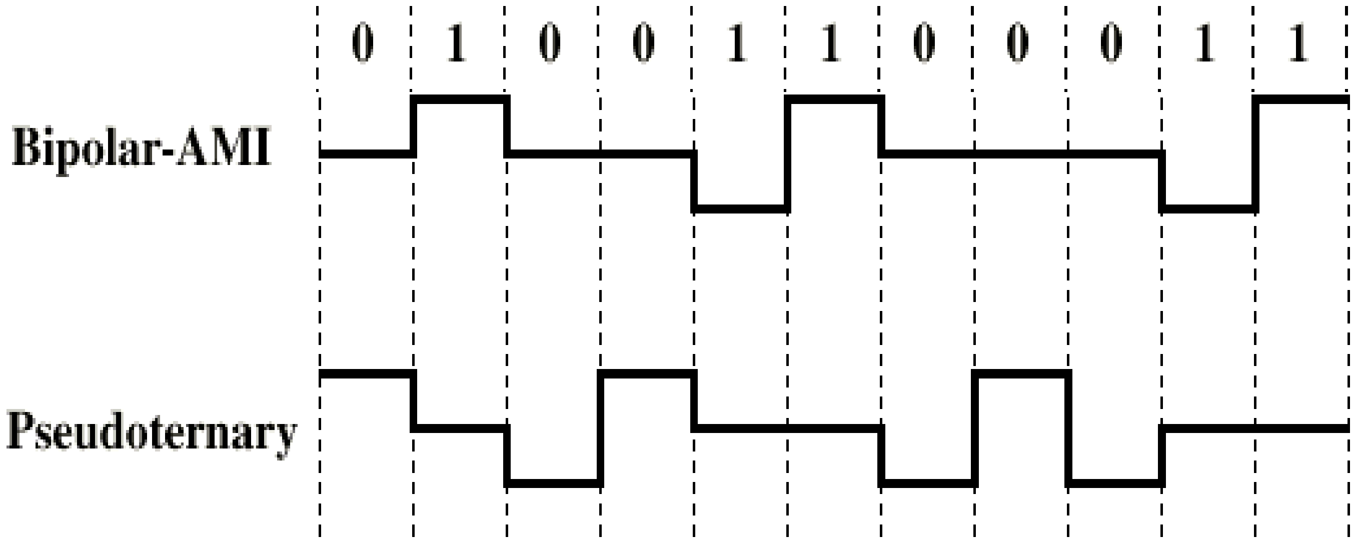
Multilevel Binary

- Use more than two levels
- Bipolar-AMI
  - zero represented by no line signal
  - one represented by positive or negative pulse
  - one pulses alternate in polarity
  - No loss of sync if a long string of ones (zeros still a problem)
  - No net dc component
  - Lower bandwidth
  - Easy error detection

Pseudoternary

- One represented by absence of line signal
- Zero represented by alternating positive and negative
- No advantage or disadvantage over bipolar-AMI

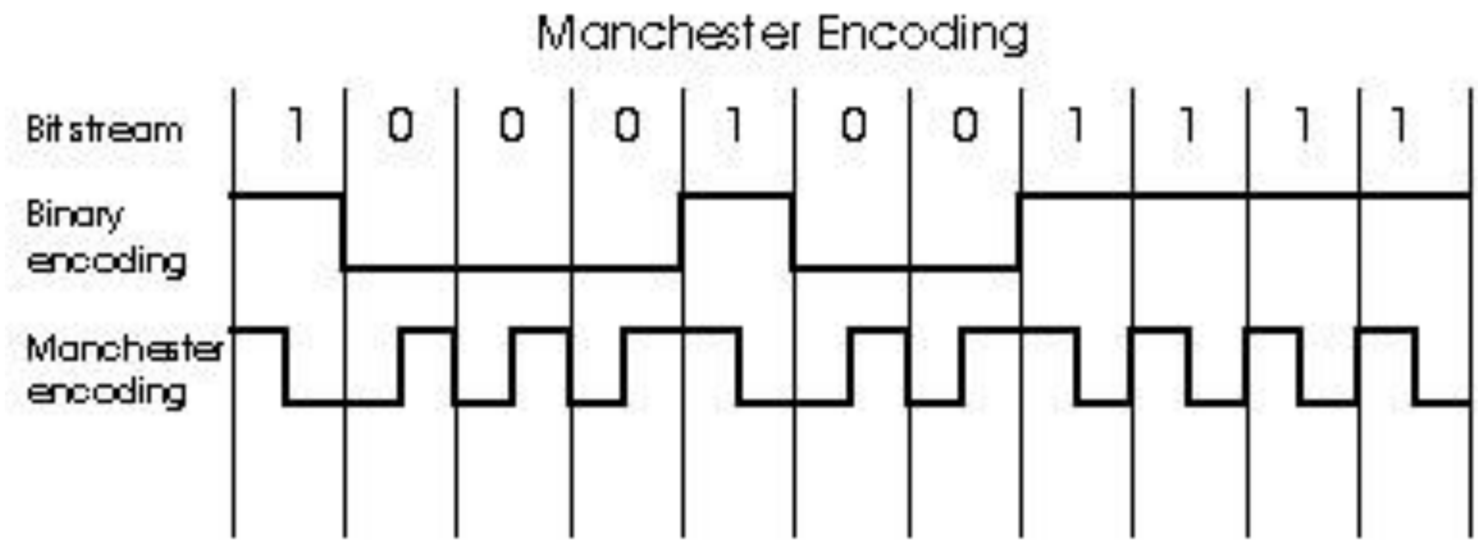
Bipolar-AMI and Pseudoternary



Biphase

- Manchester
  - Transition in middle of each bit period
  - Transition serves as clock and data
  - Low to high represents zero
  - High to low represents one
  - Used by Ethernet/IEEE 802.3 (10BaseT)
- Differential Manchester
  - Midbit transition is clocking only
  - Transition at start of a bit period represents zero
  - No transition at start of a bit period represents one
  - Note: this is a differential encoding scheme
  - Used by IEEE 802.5 (Token Ring)

Manchester encoding



- used in 10BaseT
- each bit has a transition
- allows clocks in sending and receiving nodes to synchronize to each other
  - no need for a centralized, global clock among nodes!

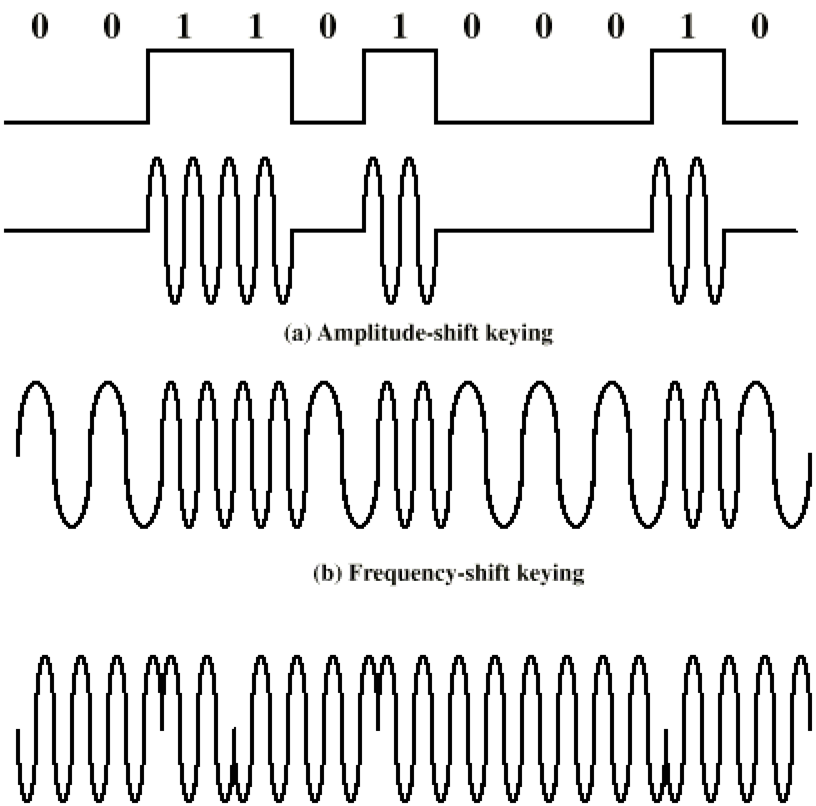
Biphase Pros and Cons

- Con
  - At least one transition per bit time and possibly two
  - Maximum modulation rate is twice NRZ
  - Requires more bandwidth
- Pros
  - Synchronization on mid bit transition (self clocking)
  - No dc component
  - Error detection
    - Absence of expected transition

Digital Data, Analog Signal

- Public telephone system
  - 300Hz to 3400Hz
  - Use modem (modulator-demodulator)
- Amplitude shift keying (ASK)
- Frequency shift keying (FSK)
- Phase shift keying (PSK)

Modulation Techniques



(a) Amplitude-shift keying

(b) Frequency-shift keying

(c) Phase-shift keying

Amplitude Shift Keying

- Values represented by different amplitudes of carrier
- Usually, one amplitude is zero
  - i.e. presence and absence of carrier is used
- Susceptible to sudden gain changes
- Inefficient
- Up to 1200bps on voice grade lines
- Used over optical fiber

Frequency Shift Keying

- Values represented by different frequencies (near carrier)
- Less susceptible to error than ASK
- Up to 1200bps on voice grade lines
- High frequency radio
- Even higher frequency on LANs using co-ax

Phase Shift Keying

- Phase of carrier signal is shifted to represent data
- Differential PSK
  - Phase shifted relative to previous transmission rather than some reference signal

Quadrature PSK

- More efficient use by each signal element representing more than one bit
  - e.g. shifts of $\pi/2$ (90^o)
  - Each element represents two bits
  - Can use 8 phase angles and have more than one amplitude
  - 9600bps modem use 12 angles , four of which have two amplitudes

Analog Data, Digital Signal

- Digitization
  - Conversion of analog data into digital data
  - Digital data can then be transmitted using NRZ-L
  - Digital data can then be transmitted using code other than NRZ-L
  - Digital data can then be converted to analog signal
  - Analog to digital conversion done using a codec
  - Pulse Code Modulation - PCM
  - Delta modulation

Pulse Code Modulation(PCM) (1)

- If a signal is sampled at regular intervals at a rate higher than twice the highest signal frequency, the samples contain all the information of the original signal
  - Voice data limited to below 4000Hz
  - Require 8000 sample per second
- Analog samples (Pulse Amplitude Modulation, PAM)
- Each sample assigned digital value

Pulse Code Modulation(PCM) (2)

- 4 bit system gives 16 levels
- Quantized
  - Quantizing error or noise
  - Approximations mean it is impossible to recover original exactly
- Coding
  - 8 bit sample gives 256 levels
- Quality comparable with analog transmission
- 8000 samples per second of 8 bits each gives 64kbps

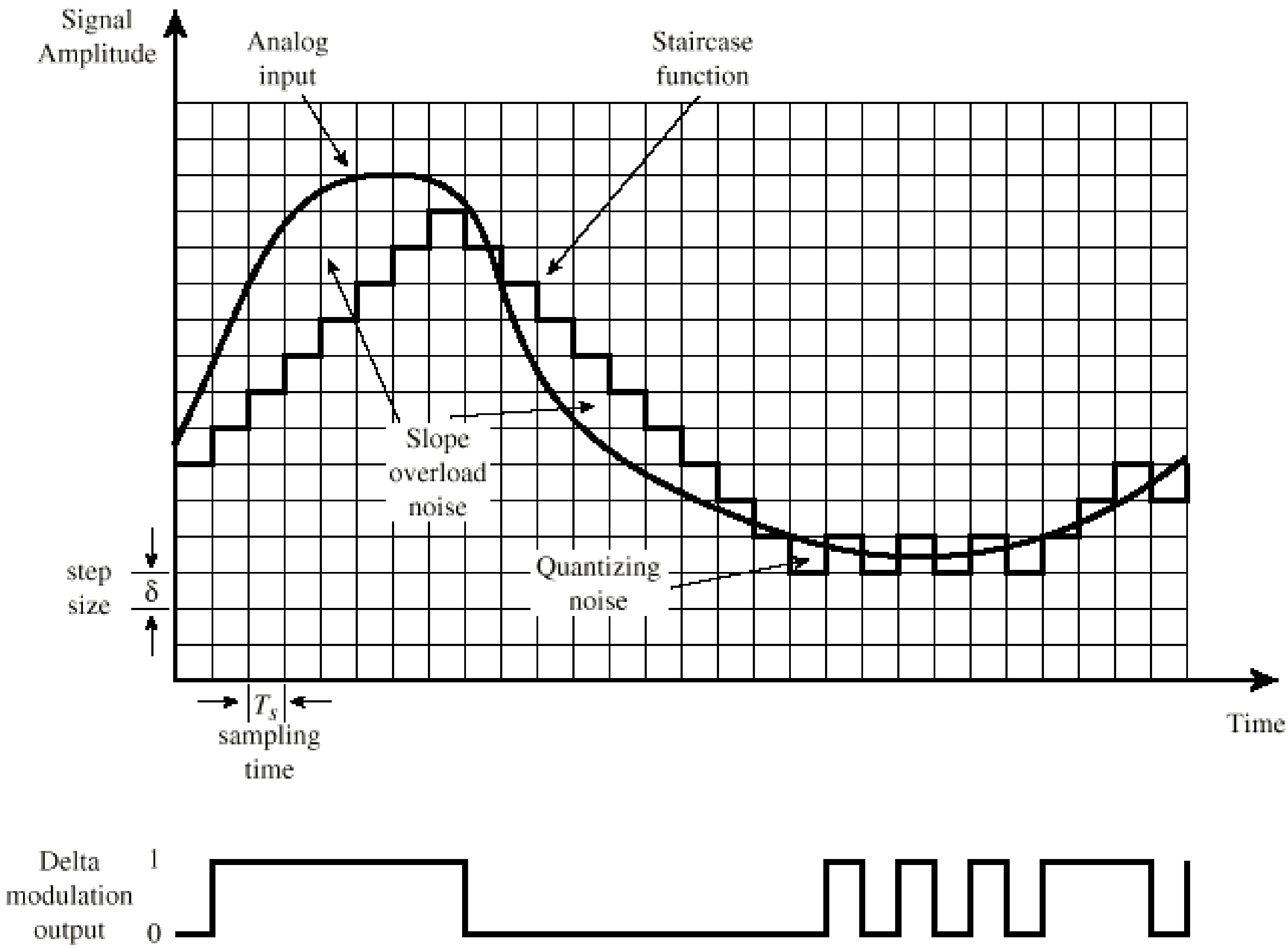
Nonlinear Encoding

- Quantization levels not evenly spaced
- Reduces overall signal distortion
- Can also be done by companding

Delta Modulation

- Analog input is approximated by a staircase function
- Move up or down one level (δ) at each sample interval
- Binary behavior
  - Function moves up or down at each sample interval

Delta Modulation - example



Analog Data, Analog Signals

- Why modulate analog signals?
  - Higher frequency can give more efficient transmission
  - Permits frequency division multiplexing
- Types of modulation
  - Amplitude
  - Frequency
  - Phase

Spread Spectrum

- Analog or digital data
- Analog signal
- Spread data over wide bandwidth
- Makes jamming and interception harder
- Frequency hoping
  - Signal broadcast over seemingly random series of frequencies
  - Invented by a Hollywood star（Hedy Lamarr）
- Direct Sequence
  - Each bit is represented by multiple bits in transmitted signal
  - Chipping code

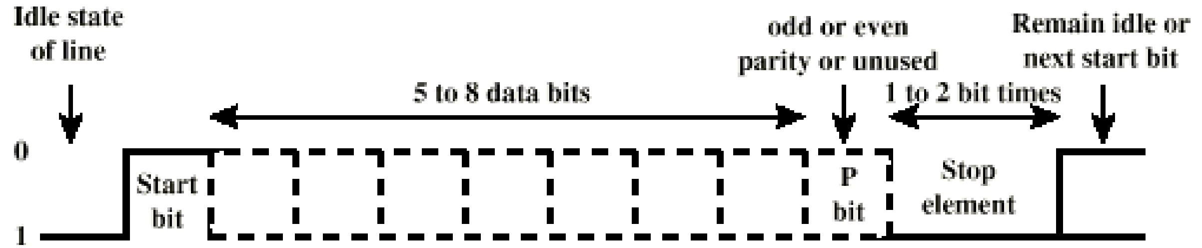
Asynchronous and Synchronous Transmission

- Timing problems require a mechanism to synchronize the transmitter and receiver
- Two solutions
  - Asynchronous
  - Synchronous

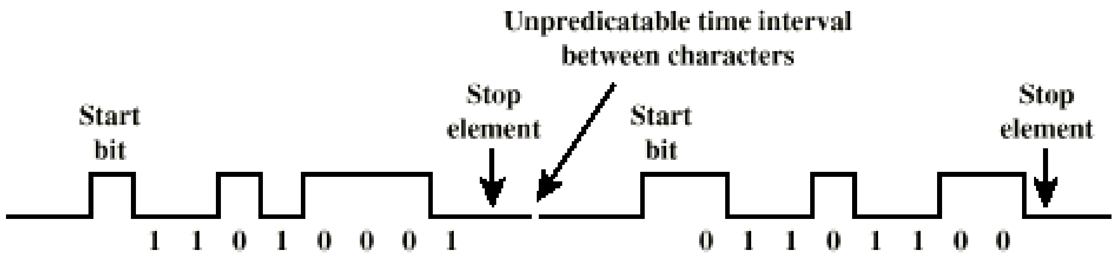
Asynchronous

- Data transmitted on character at a time
  - 5 to 8 bits
- Timing only needs maintaining within each character
- Resync with each character

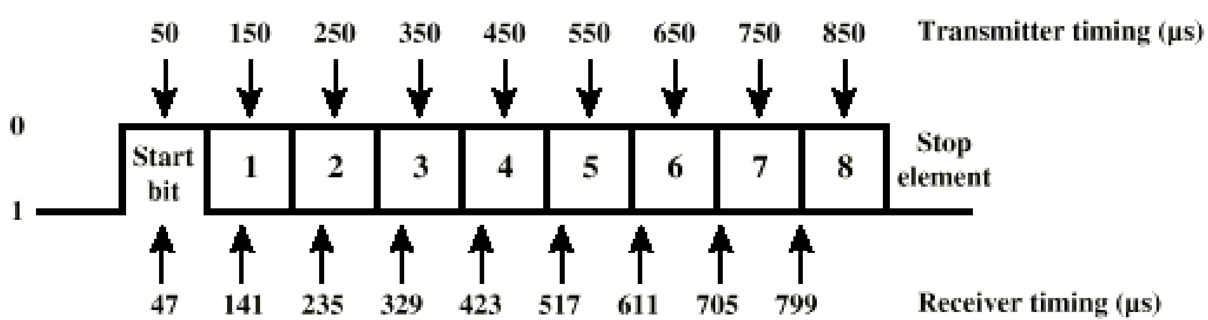
Asynchronous (diagram)



(a) Character format



(b) 8-bit asynchronous character stream



(c) Effect of timing error

Asynchronous - Behavior

- In a steady stream, interval between characters is uniform (length of stop element)
- In idle state, receiver looks for transition 1 to 0
- Then samples next seven intervals (char length)
- Then looks for next 1 to 0 for next char
- Simple
- Cheap
- Overhead of 2 or 3 bits per char (~20%)
- Good for data with large gaps (keyboard)

Synchronous - Bit Level

- Block of data transmitted without start or stop bits
- Clocks must be synchronized
- Can use separate clock line
  - Good over short distances
  - Subject to impairments
- Embed clock signal in data
  - Manchester encoding
  - Carrier frequency (analog)

Synchronous - Block Level

- Need to indicate start and end of block
- Use preamble and postamble
  - e.g. series of SYN (hex 16) characters
  - e.g. block of 11111111 patterns ending in 11111110
- More efficient (lower overhead) than async

Physical Media

- physical link: transmitted data bit propagates across link
- guided media:
  - signals propagate in solid media: copper, fiber
- unguided media:
  - signals propagate freelye.g., radio

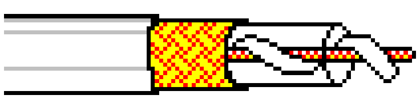
Twisted Pair (TP)

- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps ethernet
  - Category 5 TP: 100Mbps ethernet

Physical Media: coax, fiber

Coaxial cable:

- wire (signal carrier) within a wire (shield)
  - baseband: single channel on cable
  - broadband: multiple channel on cable
- bidirectional
- common use in 10Mbs Ethernet



Fiber optic cable:

- glass fiber carrying light pulses
- high-speed operation:
  - 100Mbps Ethernet
  - high-speed point-to-point transmission (e.g., 5 Gps)
- low error rate

Physical media: radio

- signal carried in electromagnetic spectrum
- no physical “wire”
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

Radio link types:

- microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., waveLAN)
  - 2Mbps, 11Mbps
- wide-area (e.g., cellular)
  - e.g. CDPD, 10’s Kbps
- satellite
  - up to 50Mbps channel (or multiple smaller channels)
  - 270 Msec end-end delay
  - geosynchronous versus LEOS

Interfacing

- Data processing devices (or data terminal equipment, DTE) do not (usually) include data transmission facilities
- Need an interface called data circuit terminating equipment (DCE)
  - e.g. modem, NIC
- DCE transmits bits on medium
- DCE communicates data and control info with DTE
  - Done over interchange circuits
  - Clear interface standards required

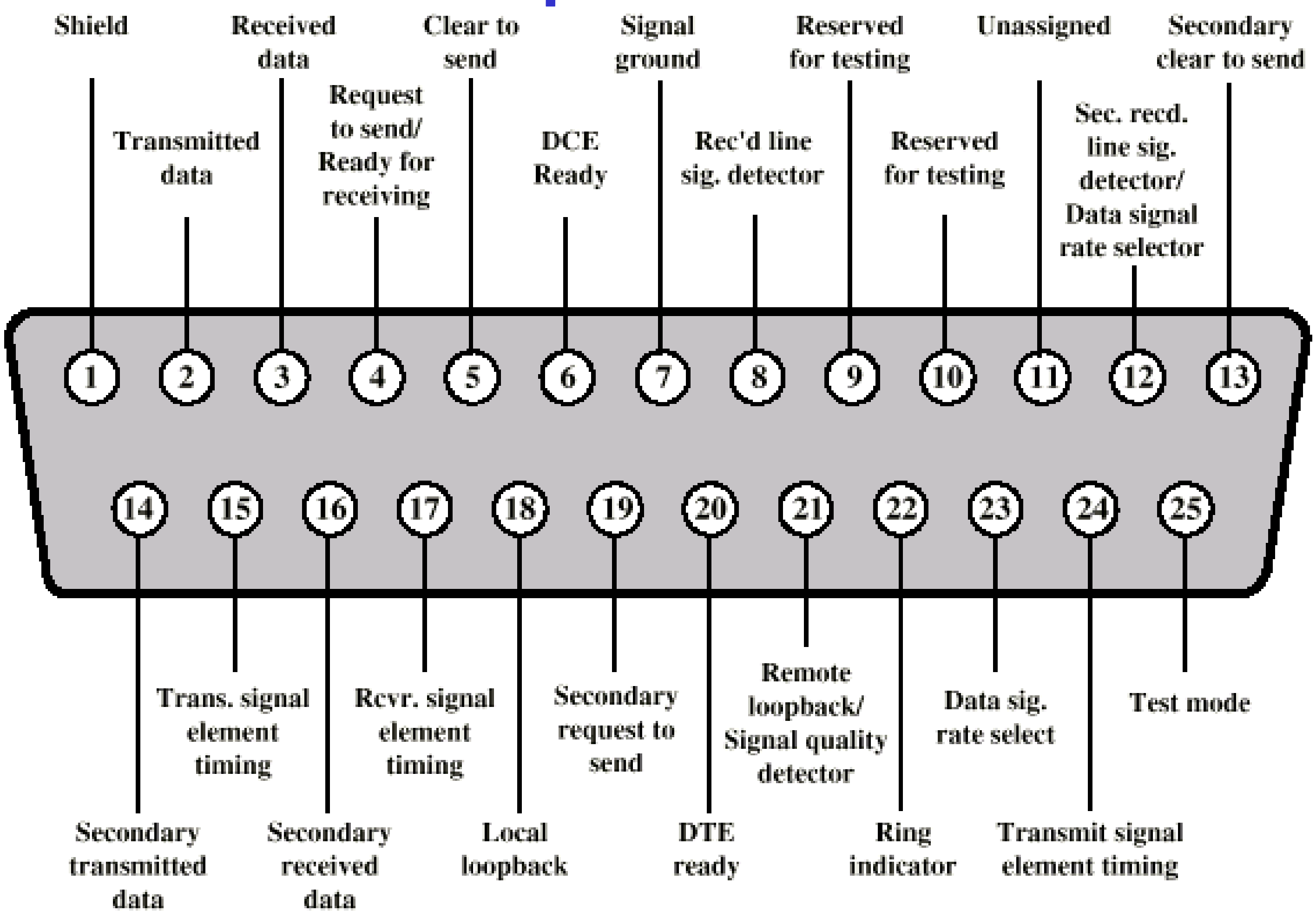
Characteristics of Interface

- Mechanical
  - Connection plugs
- Electrical
  - Voltage, timing, encoding
- Functional
  - Data, control, timing, grounding
- Procedural
  - Sequence of events

V.24/EIA-232-F

- ITU-T v.24
- Only specifies functional and procedural
  - References other standards for electrical and mechanical
- EIA-232-F (USA)
  - RS-232
  - Mechanical ISO 2110
  - Electrical v.28
  - Functional v.24
  - Procedural v.24

Mechanical Specification

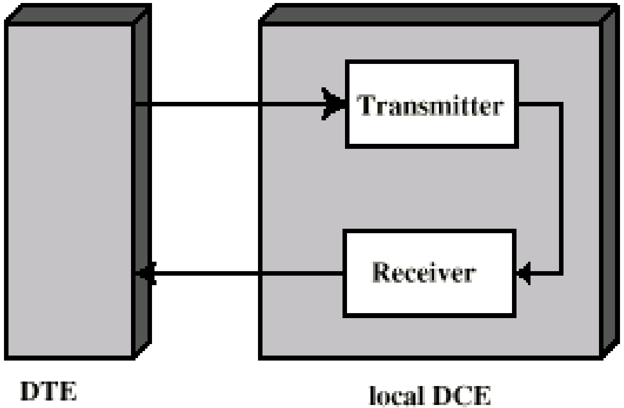


Pin Assignments for V.24/EIA-232 (DTE Connector Face)

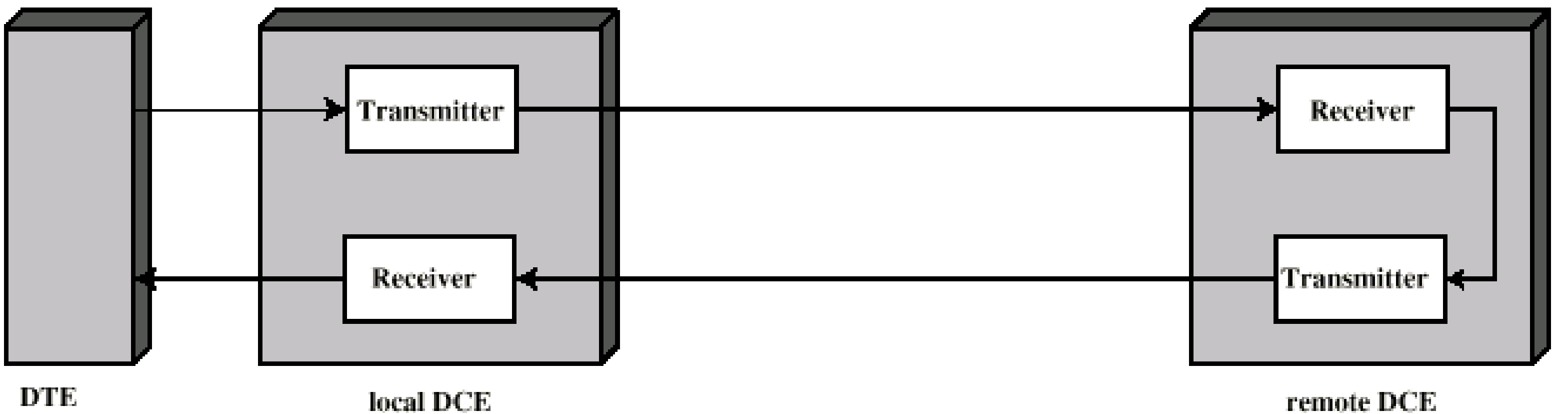
Electrical Specification

- Digital signals
- Values interpreted as data or control, depending on circuit
- More than -3v is binary 1, more than +3v is binary 0 (NRZ-L)
- Signal rate < 20kbps
- Distance <15m
- For control, more than-3v is off, +3v is on

Local and Remote Loopback



(a) Local loopback Testing

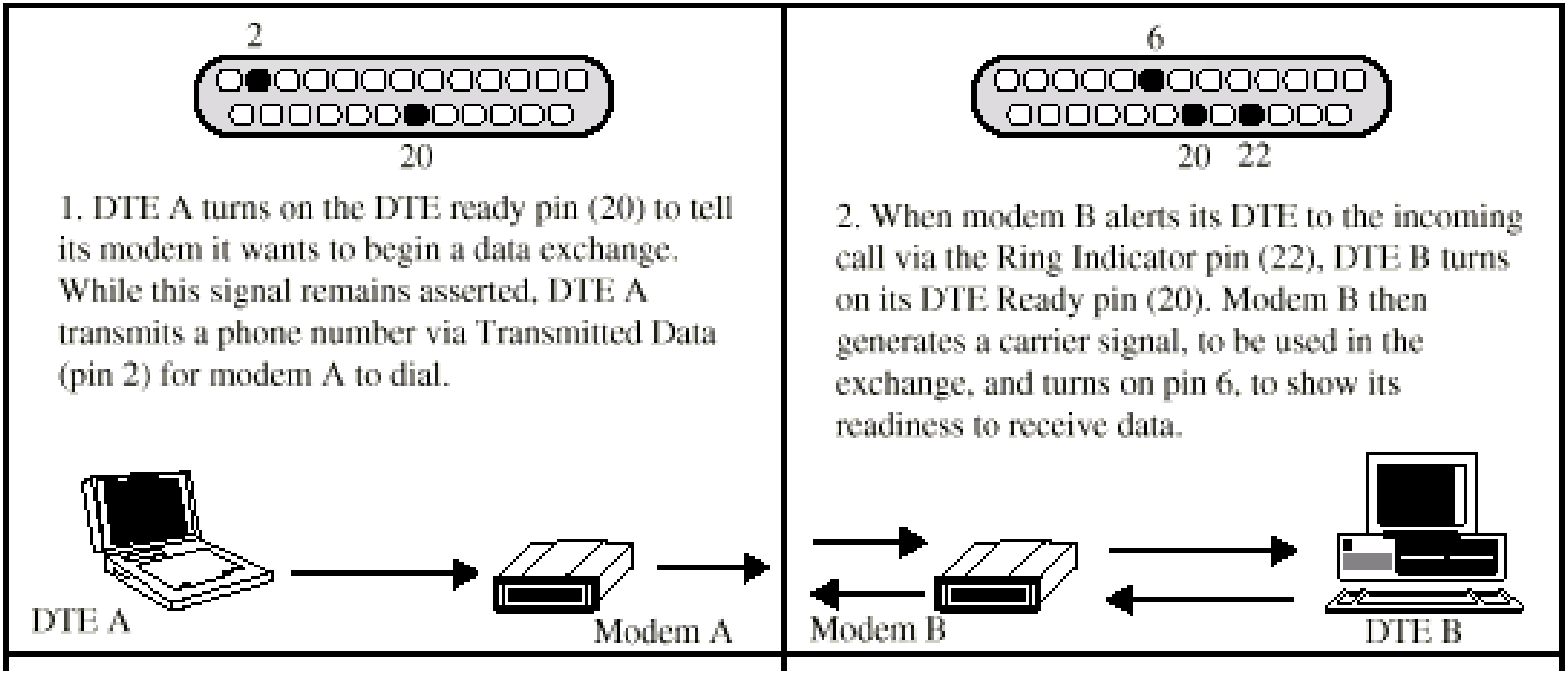


(b) Remote loopback Testing

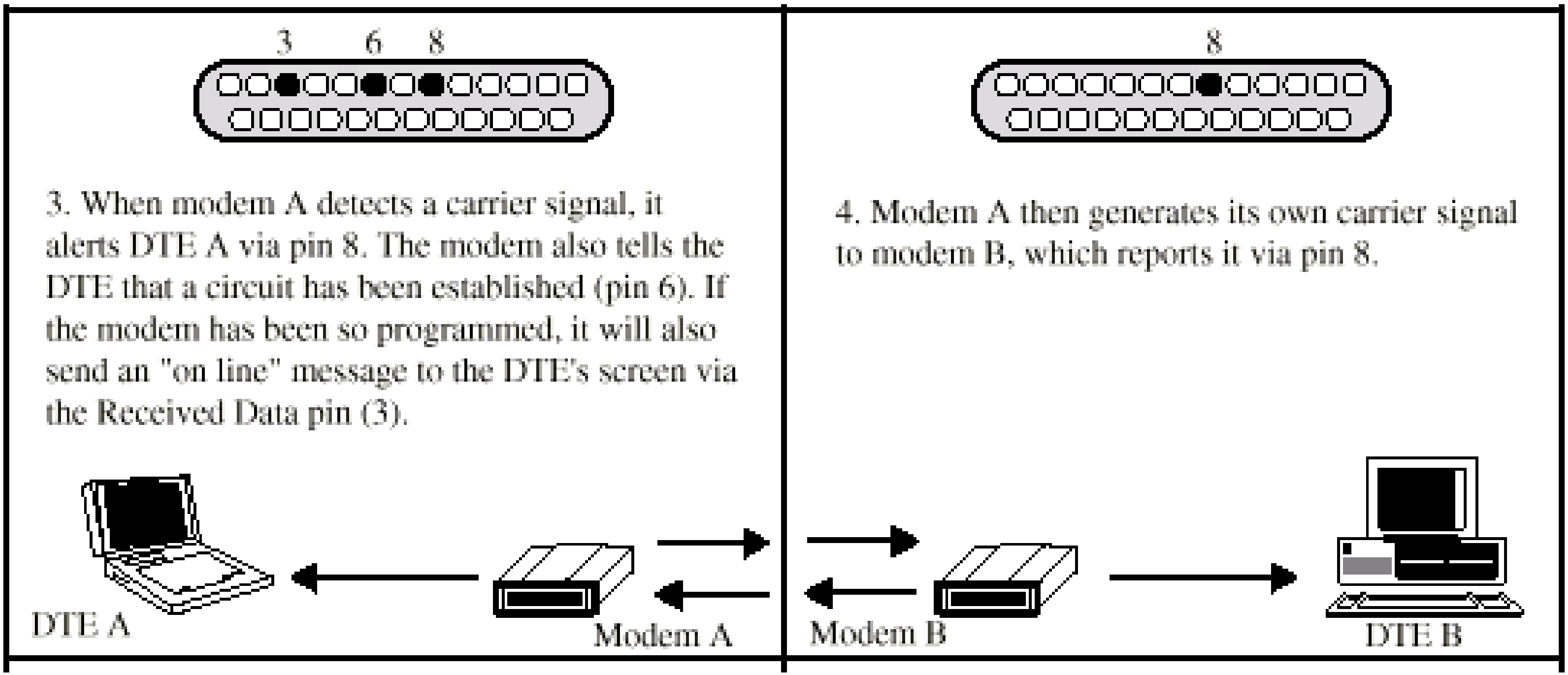
Procedural Specification

- E.g. Asynchronous private line modem
- When turned on and ready, modem (DCE) asserts DCE ready
- When DTE ready to send data, it asserts Request to Send
  - Also inhibits receive mode in half duplex
- Modem responds when ready by asserting Clear to send
- DTE sends data
- When data arrives, local modem asserts Receive Line Signal Detector and delivers data

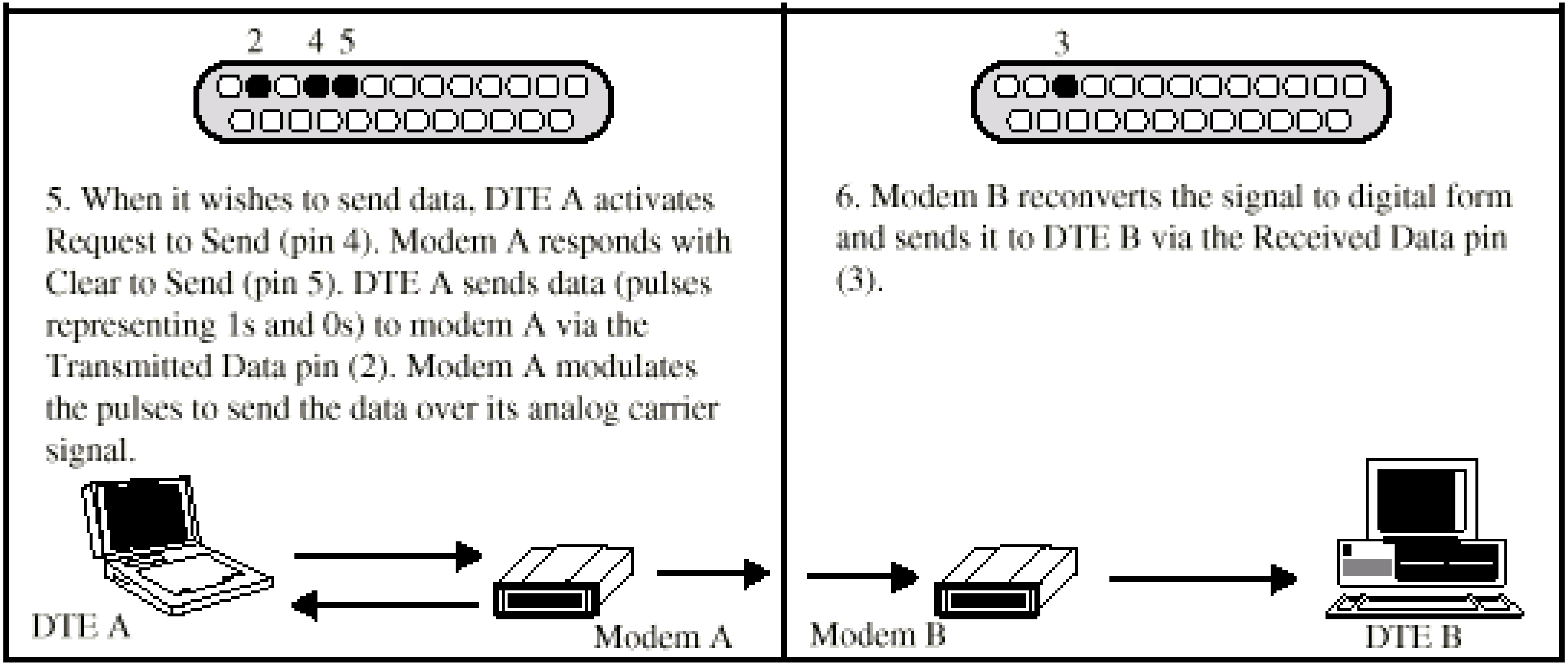
Dial Up Operation (1)



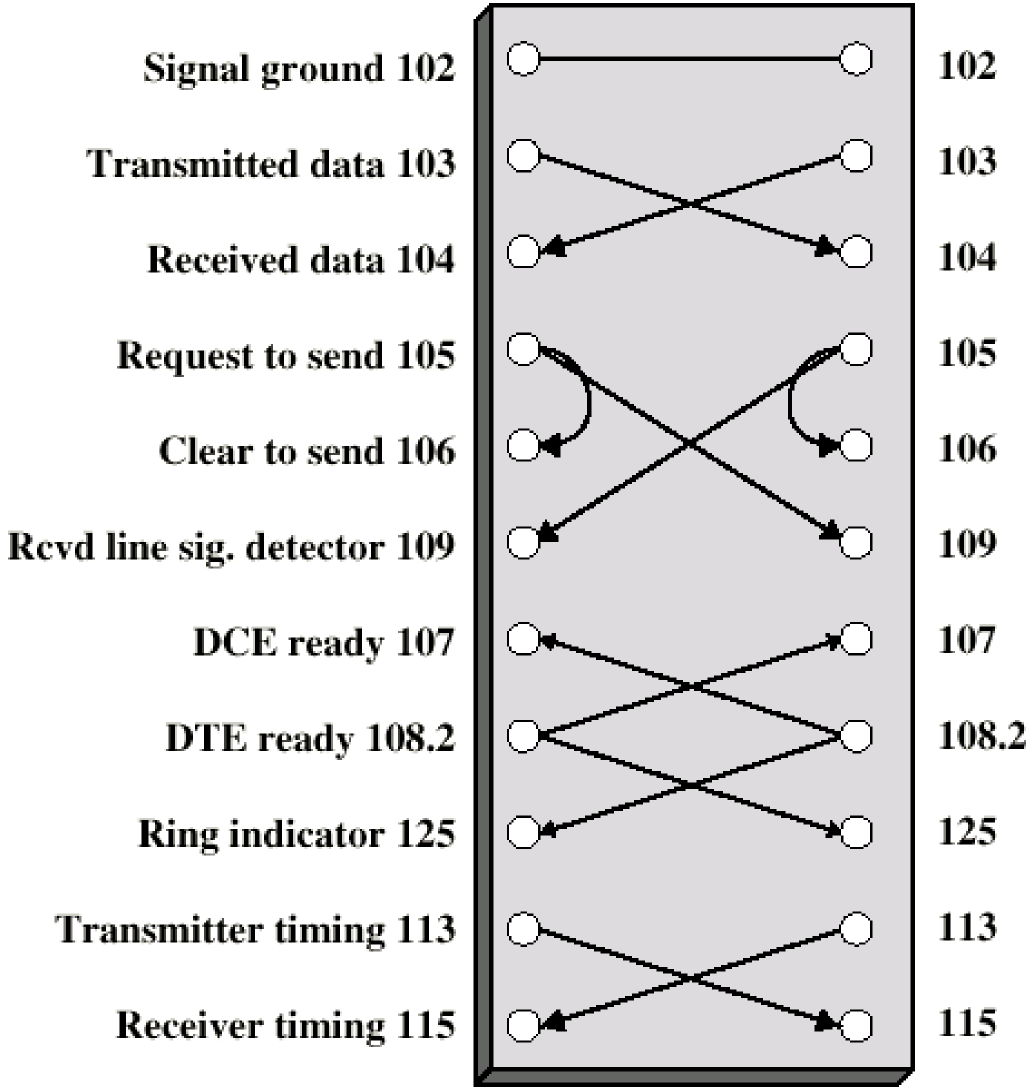
Dial Up Operation (2)



Dial Up Operation (3)



Null Modem



Signal ground 102
Transmitted data 103
Received data 104
Request to send 105
Clear to send 106
Rcvd line sig. detector 109
DCE ready 107
DTE ready 108.2
Ring indicator 125
Transmitter timing 113
Receiver timing 115
102
103
104
105
106
109
107
108.2
125
113
115

Summary

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  - Terminology
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  - Encoding Techniques
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  - Asynchronous and Synchronous Transmission
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